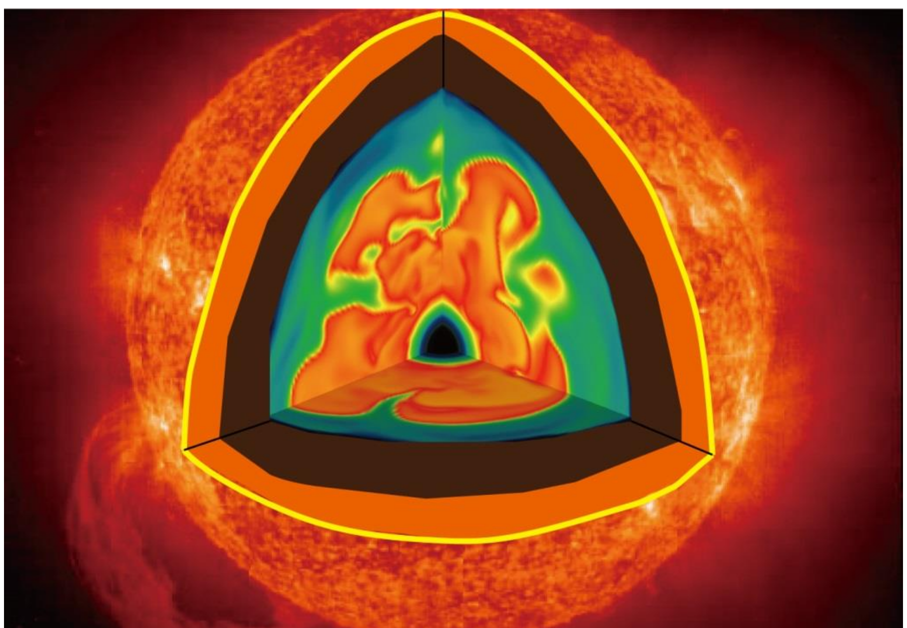
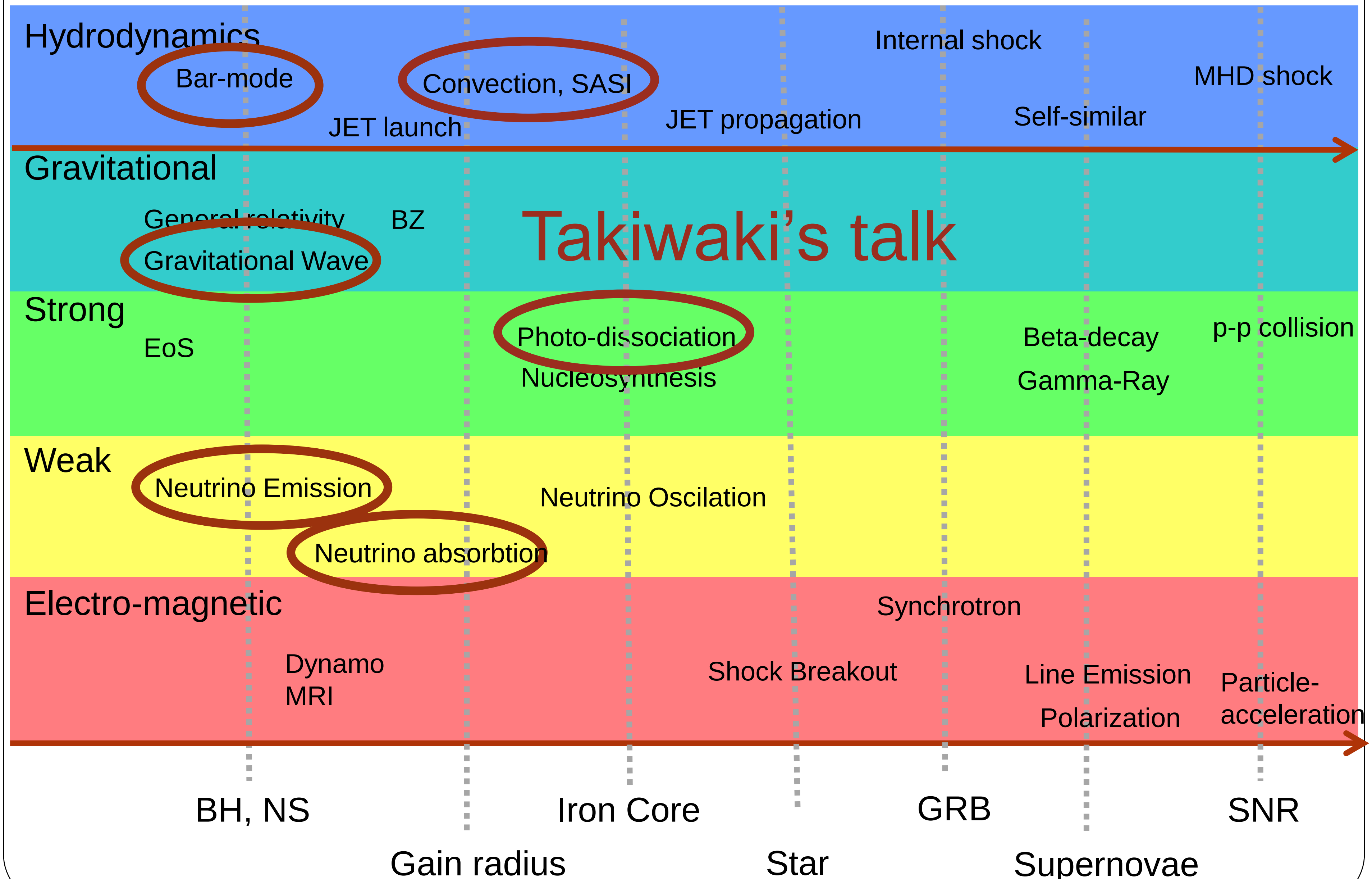
2014/8/25 GRB-SN Workshop@RIKEN

Explosion Mechanism of Core-collapse Supernovae

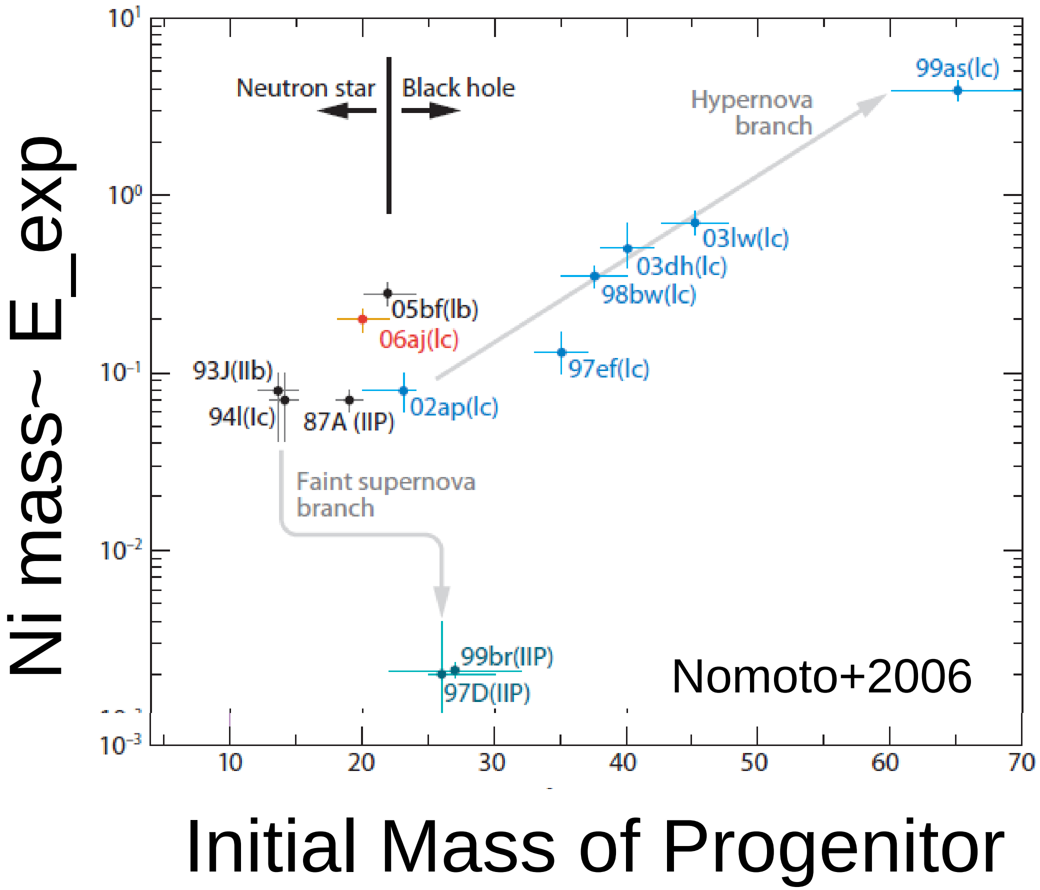


Tomoya Takiwaki
(RIKEN)

Multi-scale & Multi-physics



Various Kinds of CC supernovae



Fate of the star differs from the character of the progenitor:

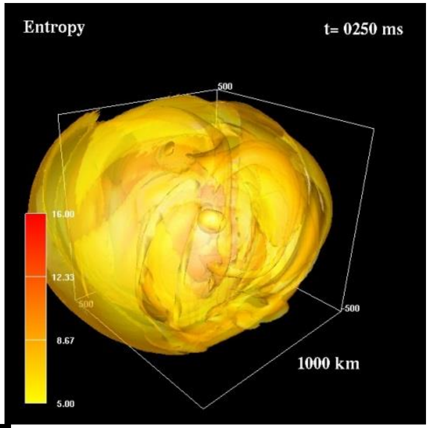
1. Mass
2. Rotation
3. Magnetic Field

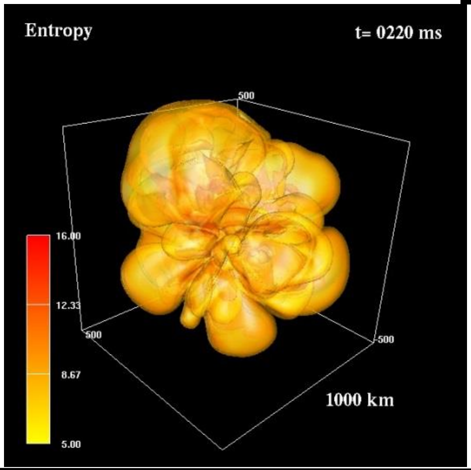
Two class of CC SNe

We focus on this

Neutrino Mechanism

Rotation





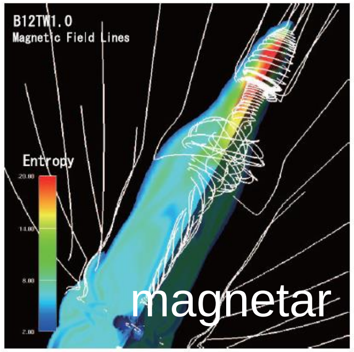
pulsar

Mass

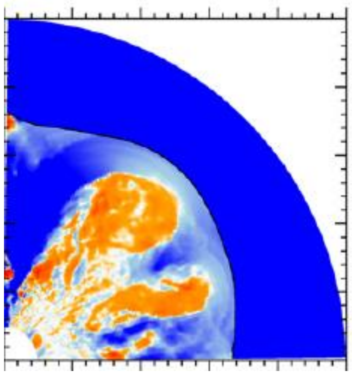
Magnetic Mechanism

Magnetic Fields

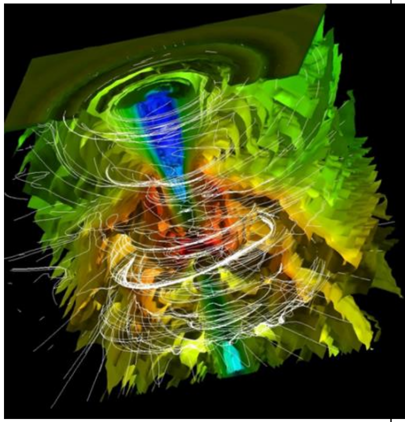
Rotation



magnetar



← Sawai's talk

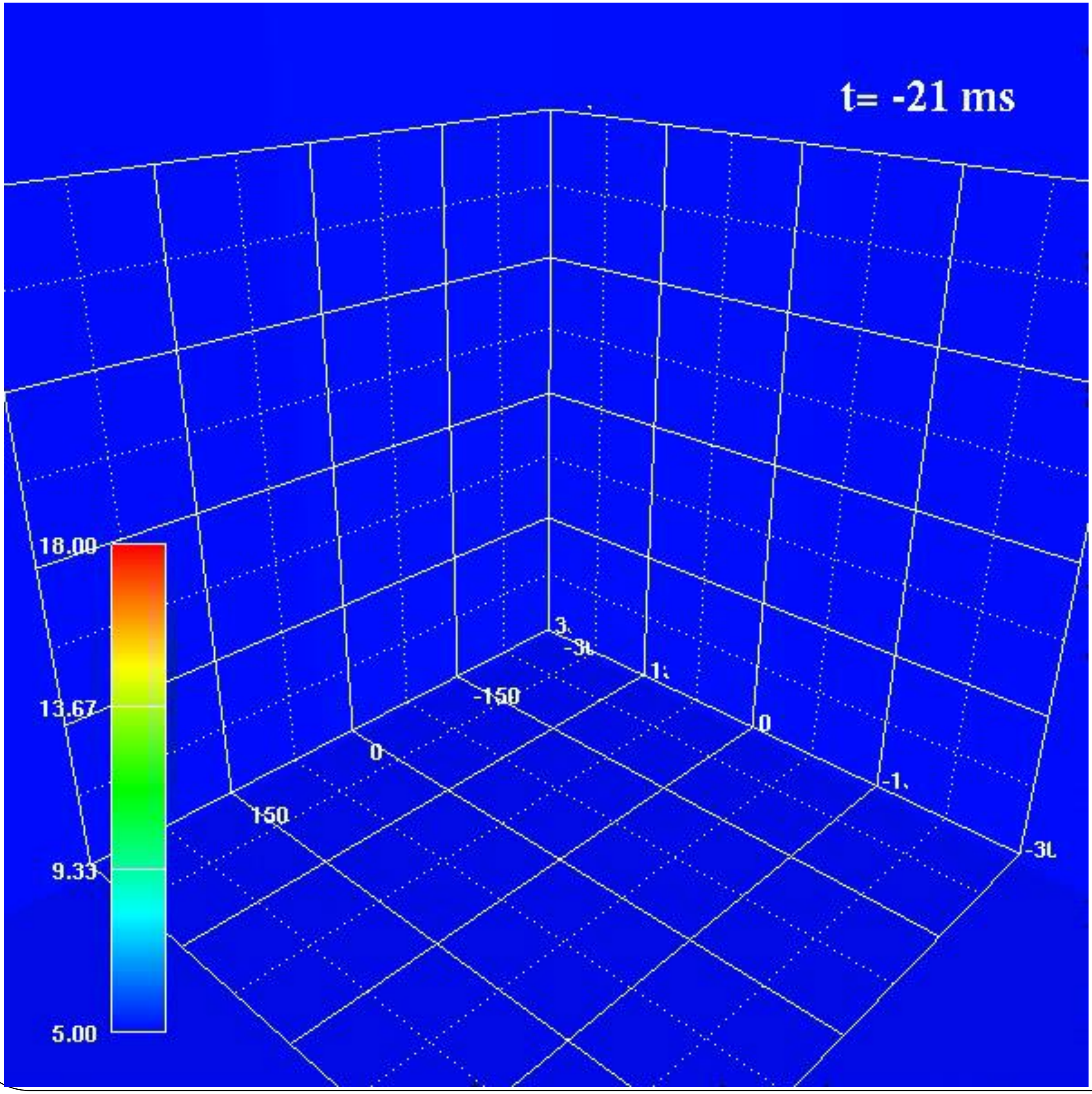


BH

↑Barkov's talk

Mass

Does the shock revive by ν-heating?



Spherical symmetric simulations

Entropy is visualized.

The answer is NO!

ν −heating alone is not enough!

That needs some help!

What helps neutrino heating?

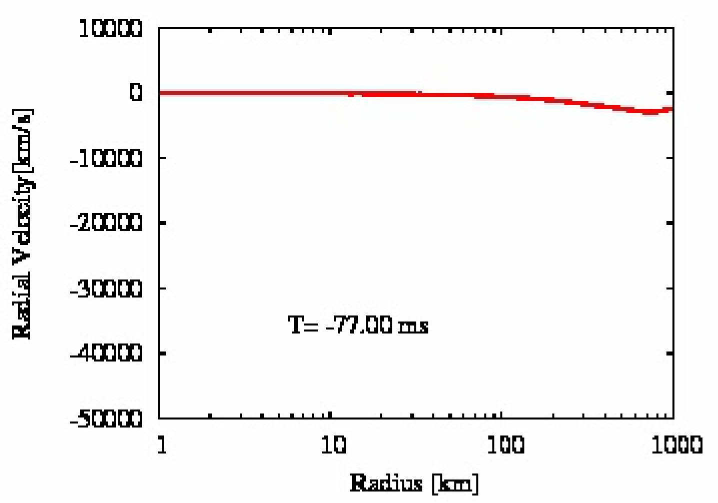
1. Convection
2. SASI
   (Standing Accretion Shock Instability)
3. Rotation
4. Magneto-Rotational Instability

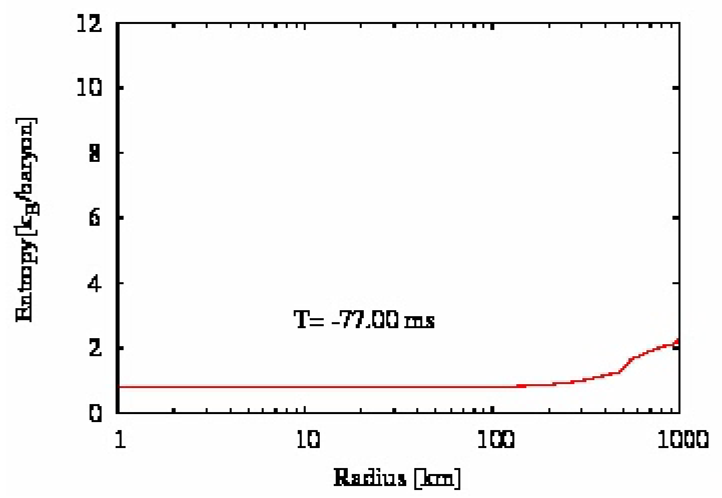
Initial setup: Shock and Entropy

Entropy:T^3/ρ

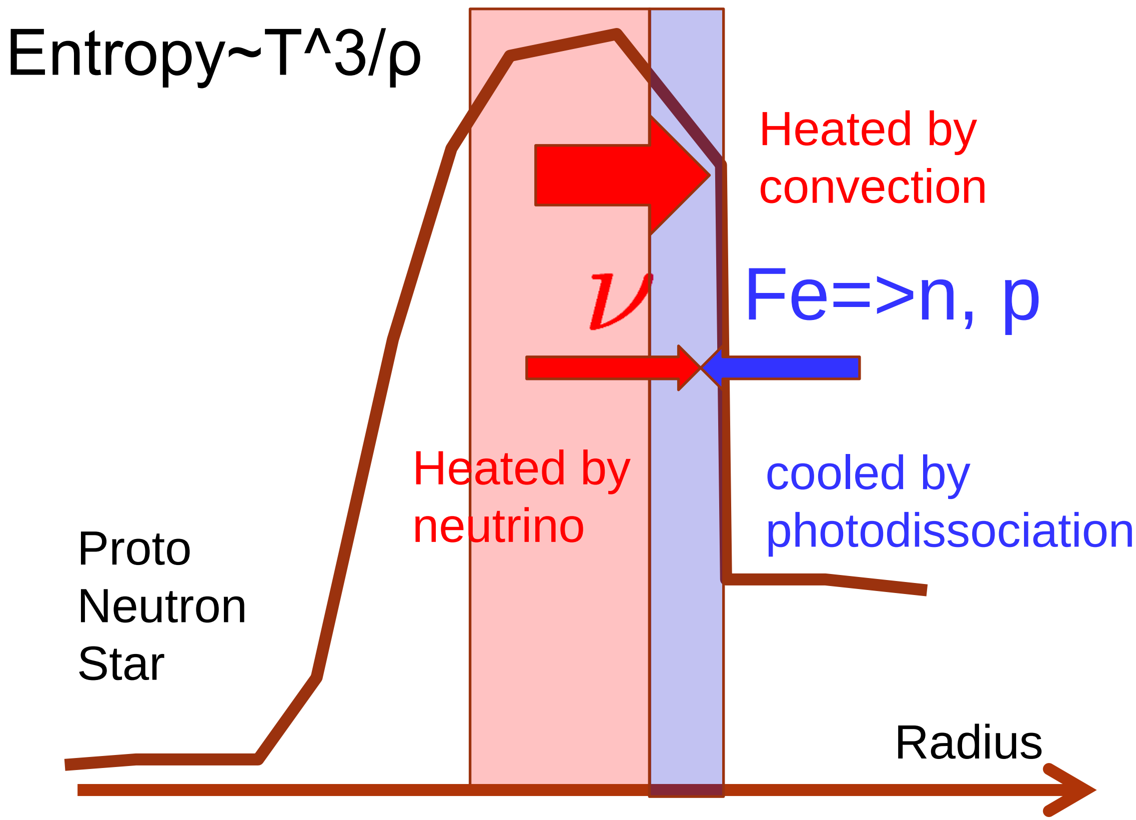
It's a good measure for the shock.

At the shock, kinetic energy is converted to heat and temperature increases(i.e. entropy also increases.)





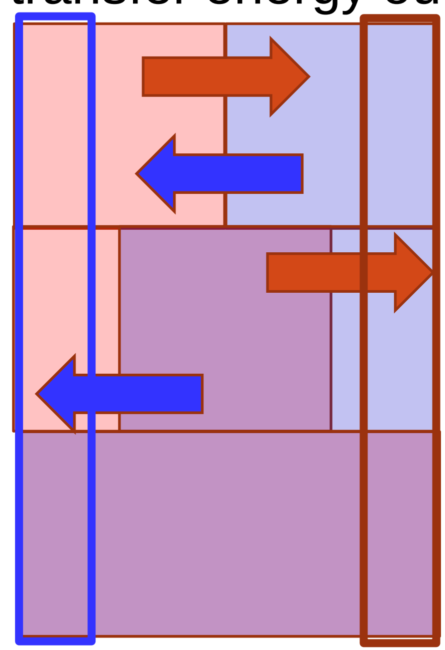
Convection



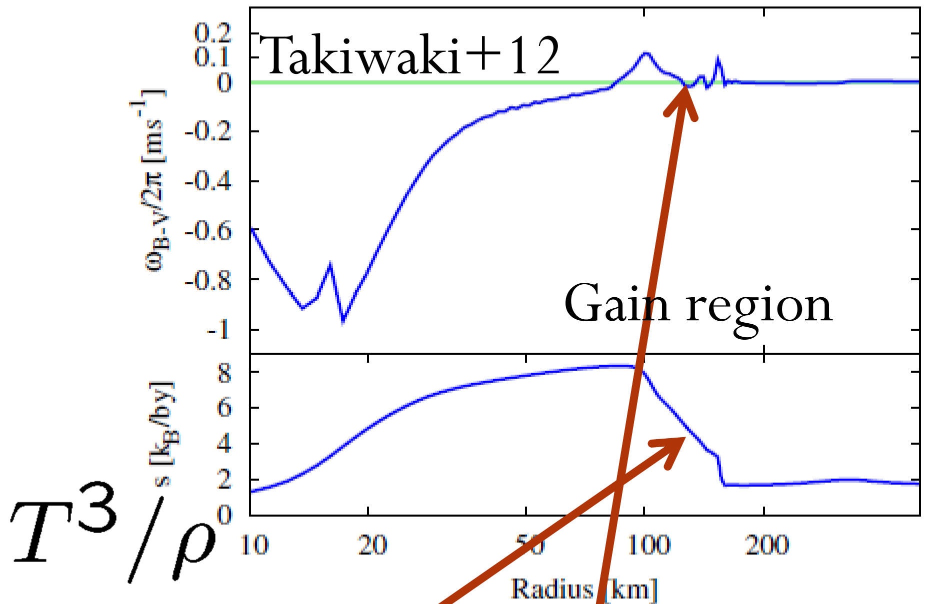
Negative entropy gradient leads Rayleigh-Taylor instability

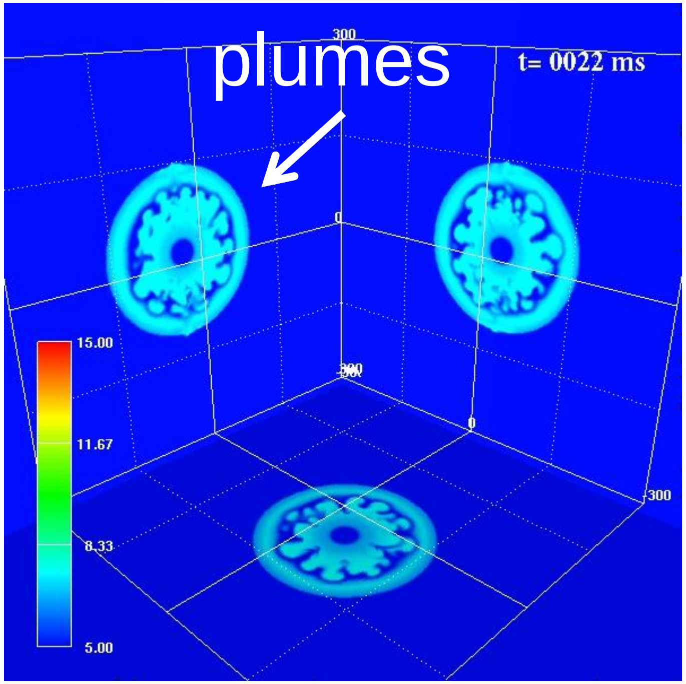
(Cold heavy matter is put over Hot light matter)

Rayleigh-Taylor convection transfer energy outward.



Convection

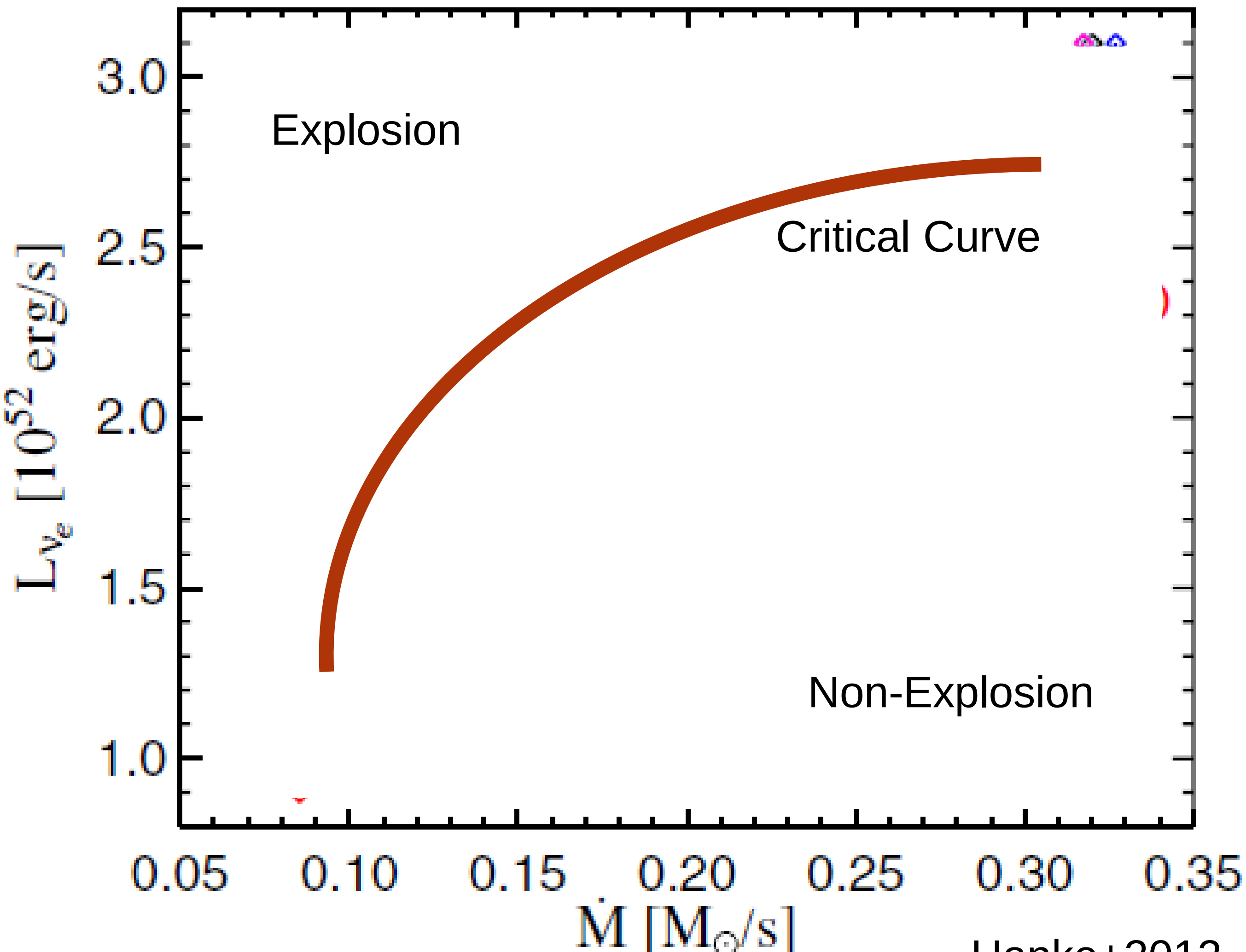




Cold heavy matter is put on the hot light matter => convective instability

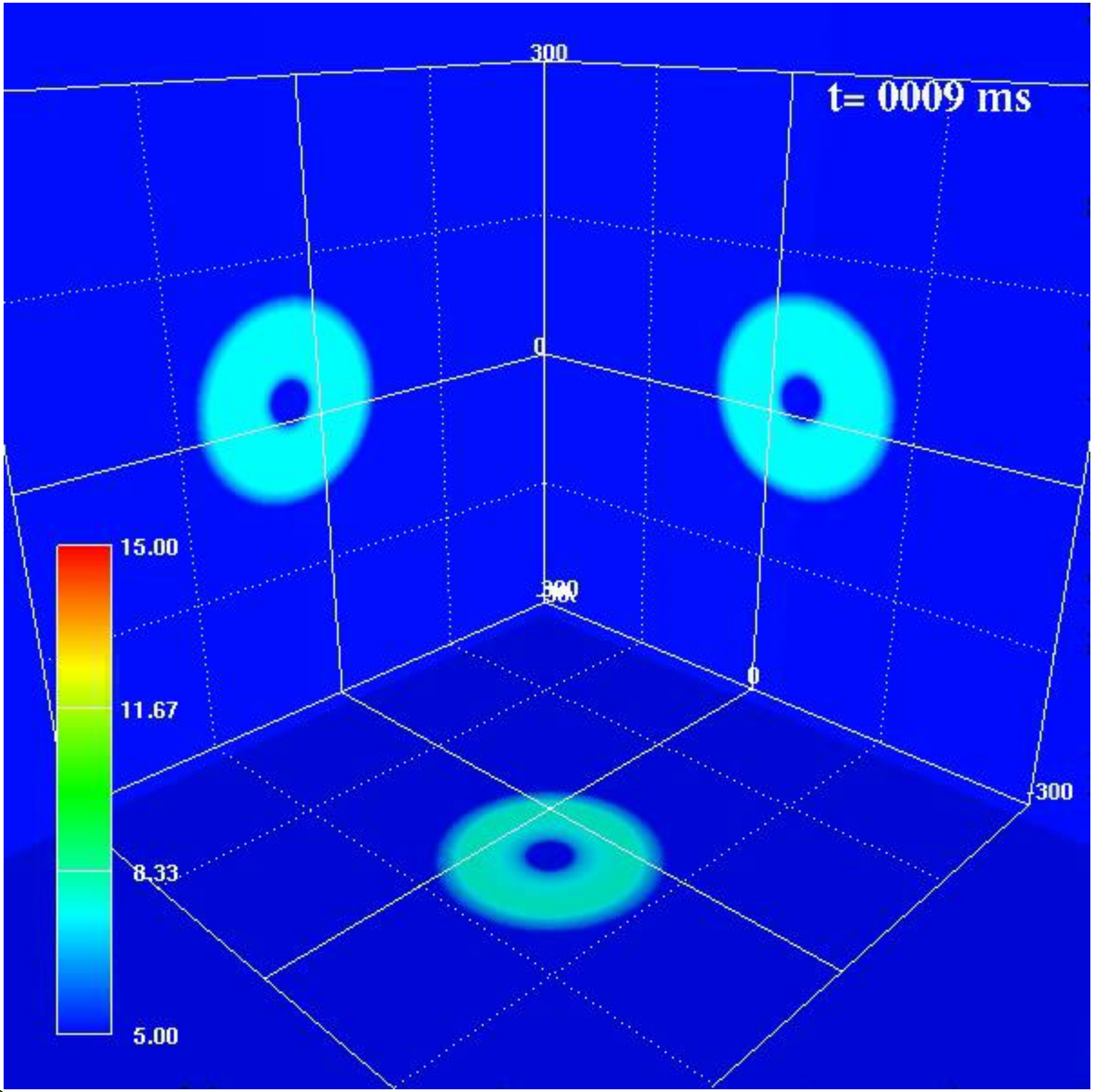
Typical growth time scale~10ms

Convection



Hanke+2012

s11.2(Light Progenitor) Ω=0rad/s



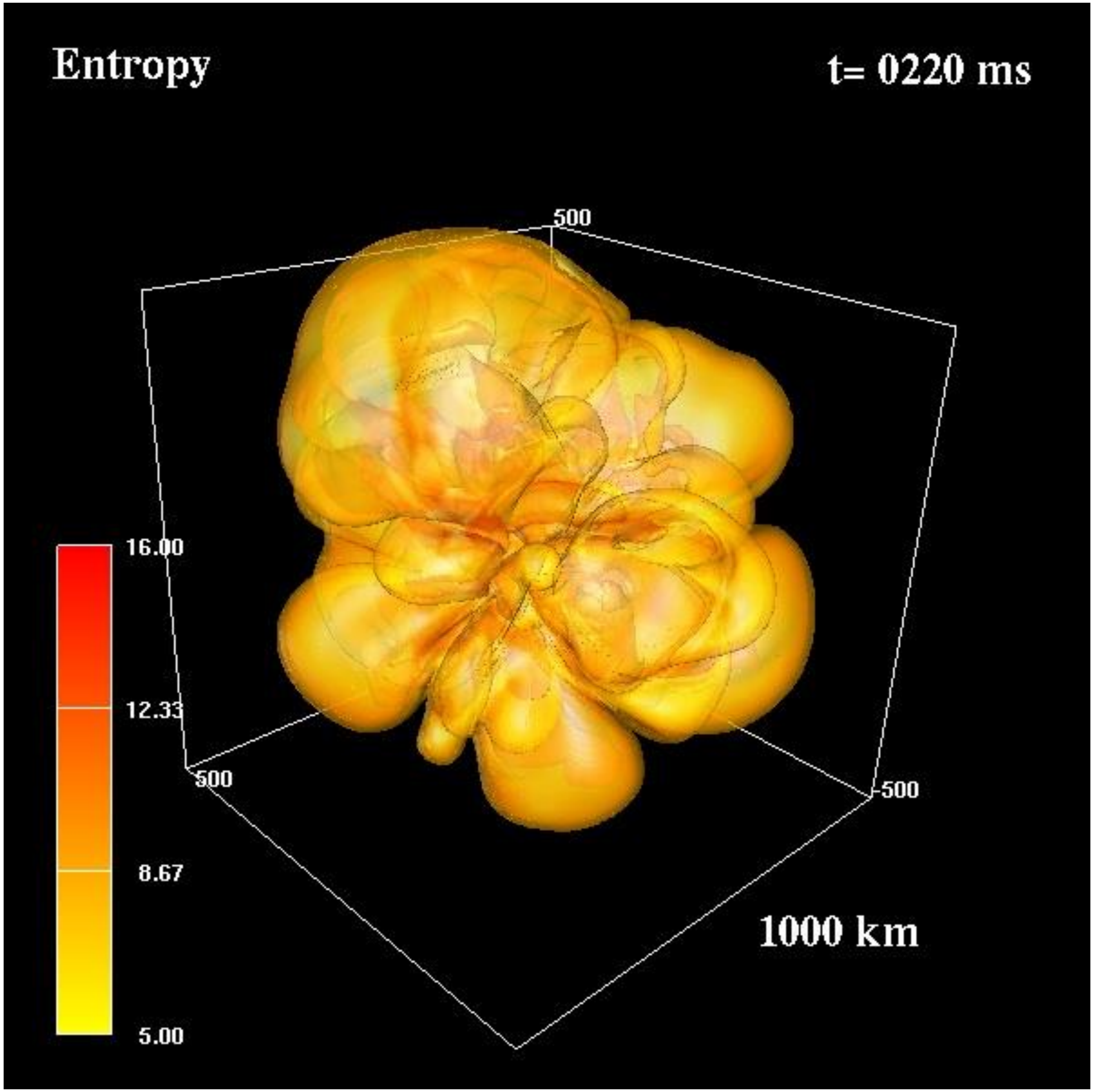
Explode!
Convection
Dominant

EoS : LS-K220

resolution :
384(r)x128(θ)x256(φ)
The finest grid

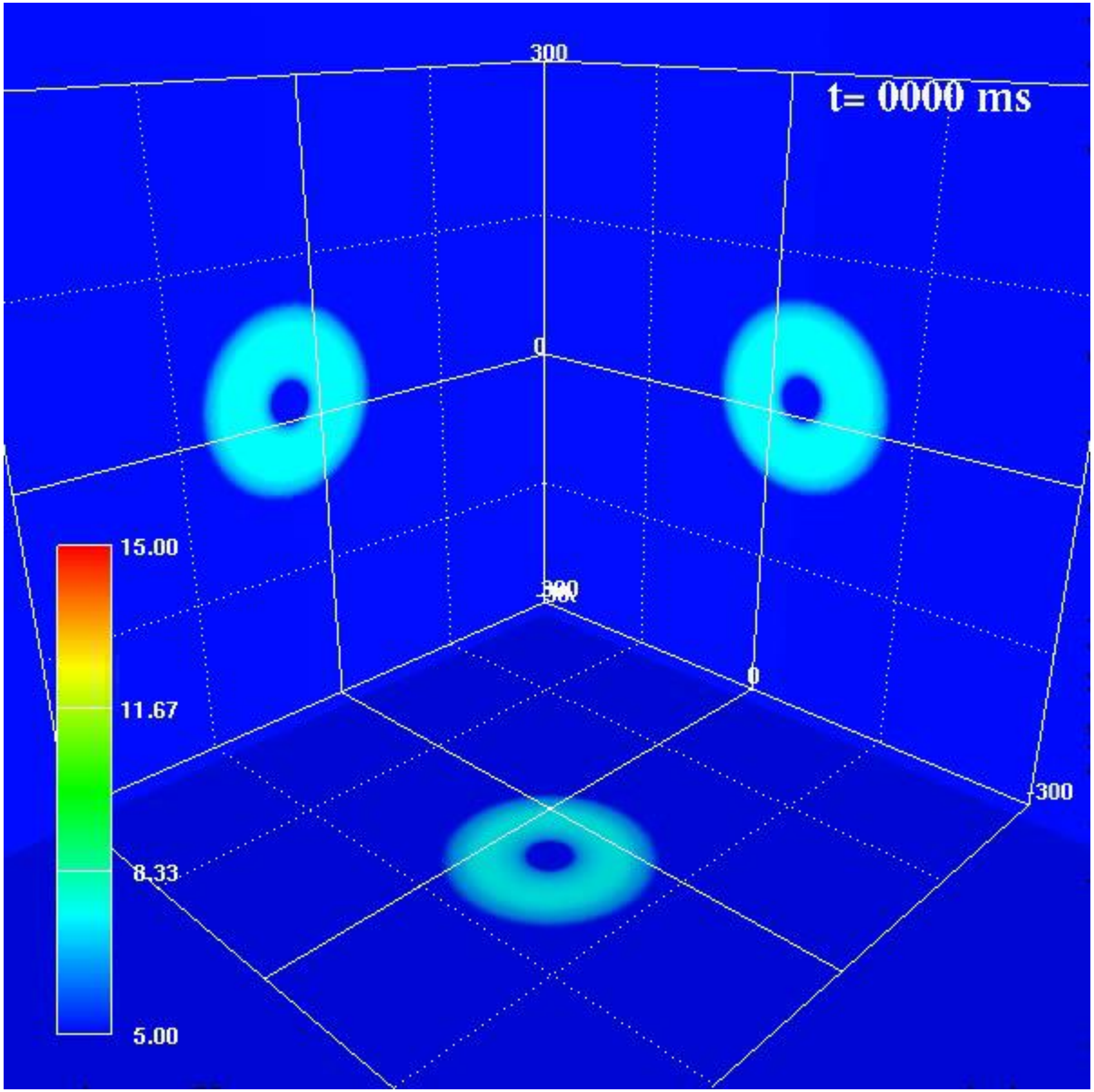
Neutrino Trasport :
Ray-by-Ray:IDSA
+Leakage
Hydro:
HLLE, 2nd order

Shape of the explosion？



Many hot bubble is observed.
That is evidence of strong convection.
=>
Non-axisymmetric polarization?

s27 Ω=0rad/s



Failed

EoS：LS-K220

resolution：
384(r)x64(θ)x128(φ)

Neutrino Transport：
Ray-by-Ray:IDSA
+Leakage

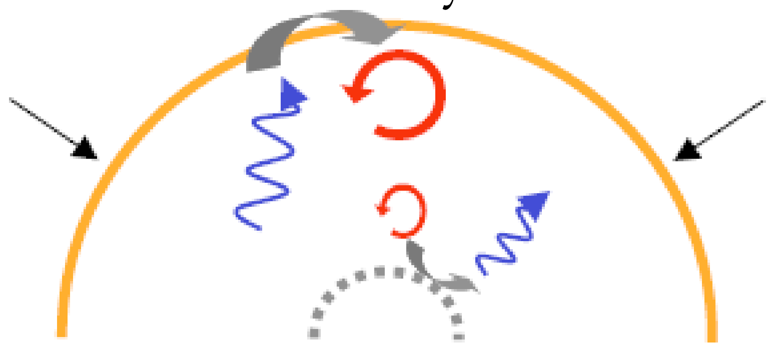
Hydro:
HLLE, 2nd order

What helps neutrino heating?

1. Convection
2. SASI
   (Standing Accretion Shock Instability)
3. Rotation
4. Magneto-Rotational Instability

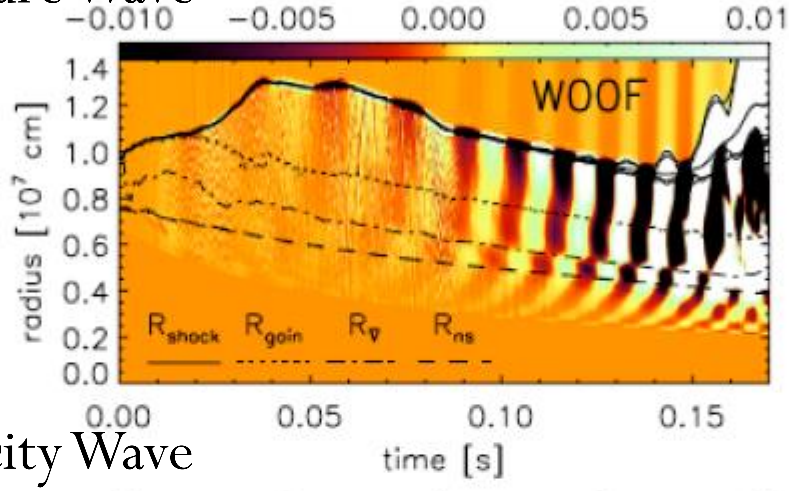
S A S I

Advective-acoustic cycle

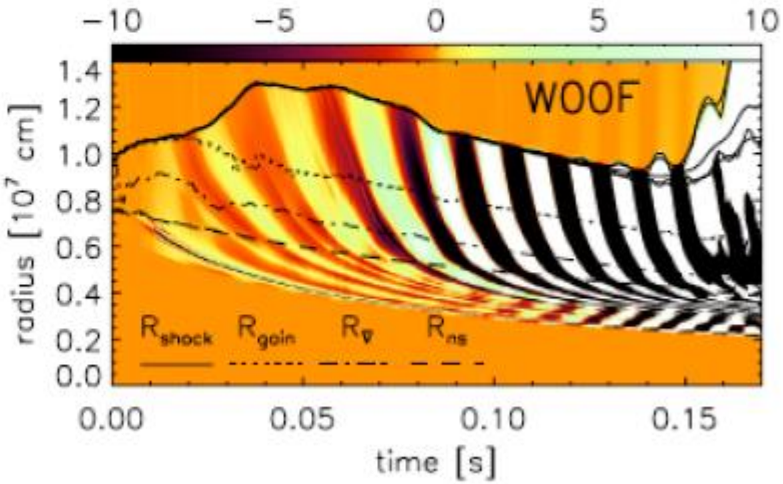


Foglizzo's slides

Pressure Wave



Vorticity Wave



Standing Accretion Shock Instability(SASI)

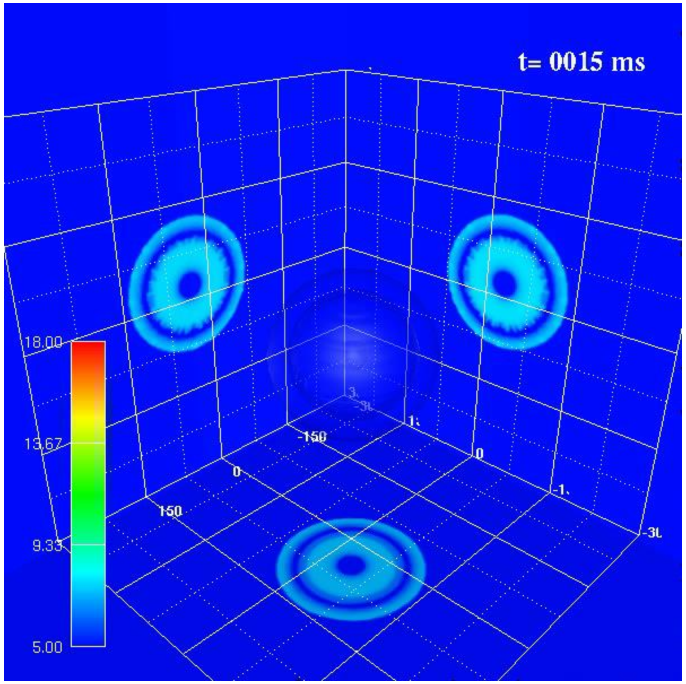
$$\tau_{\mathrm{SASI}} \sim R_{\mathrm{sh}}/v_r$$

$\dot{M}\uparrow, v_r\uparrow, \tau_{\mathrm{SASI}}$ Rapid!

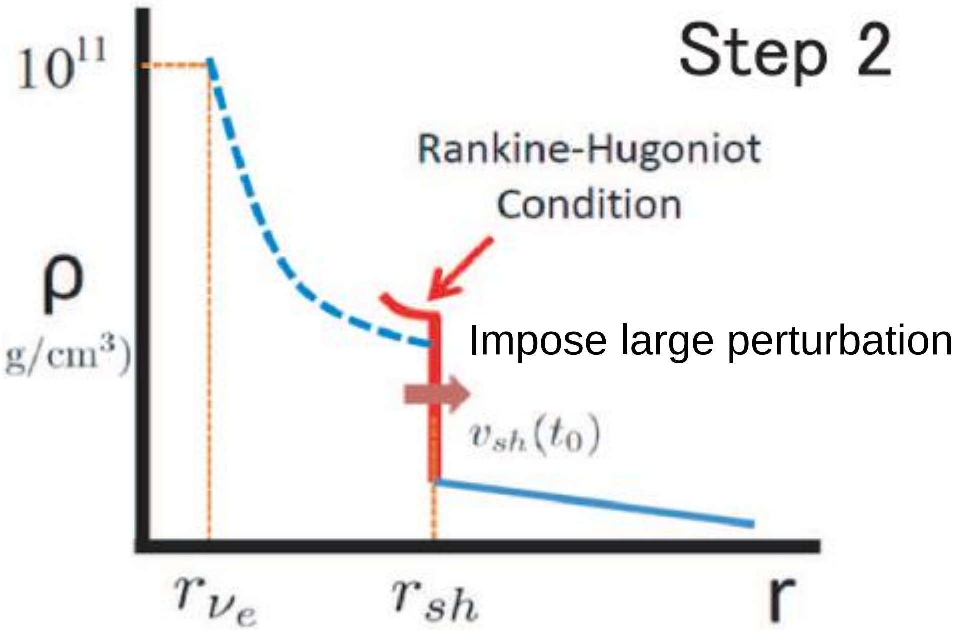
Scheck+ 2008

S A S I

2D Axi-symmetric



Takiwaki+2012

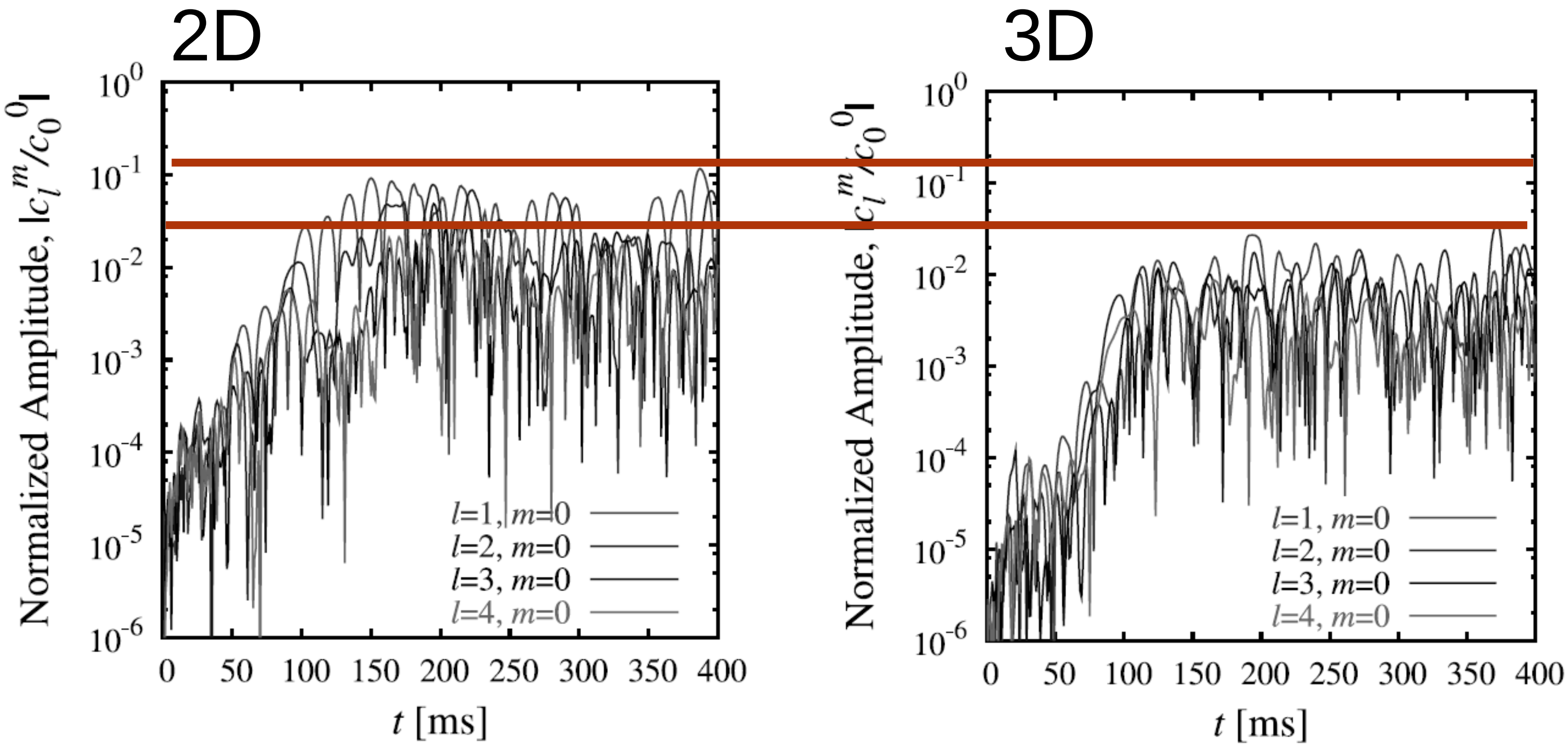


$f_{crit} \sim 0.8 \times (M_{in}/1.4M_{\odot}) \times \{1-(r_{sh}/10^8\mathrm{cm})\}$

Nagakura+2012

SASI focus energy at a direction!
0.7-0.6 of increase in total pressure can revive the shock.

S A S I in 2D and 3D



Iwakami+08

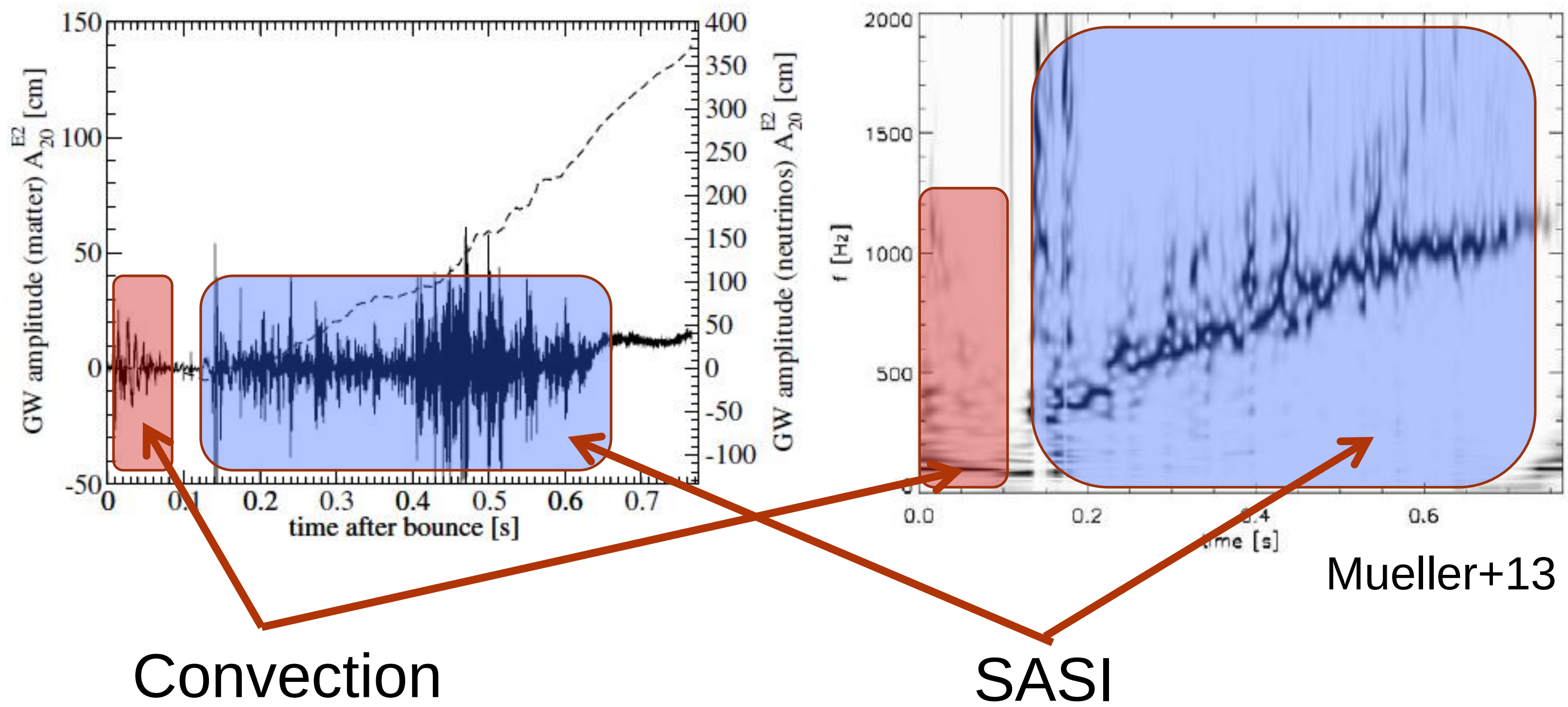
Shock radius is decomposed by spherical harmonics.

The amplitude become small in 3D.

The shock revival by SASI seems to be difficult.

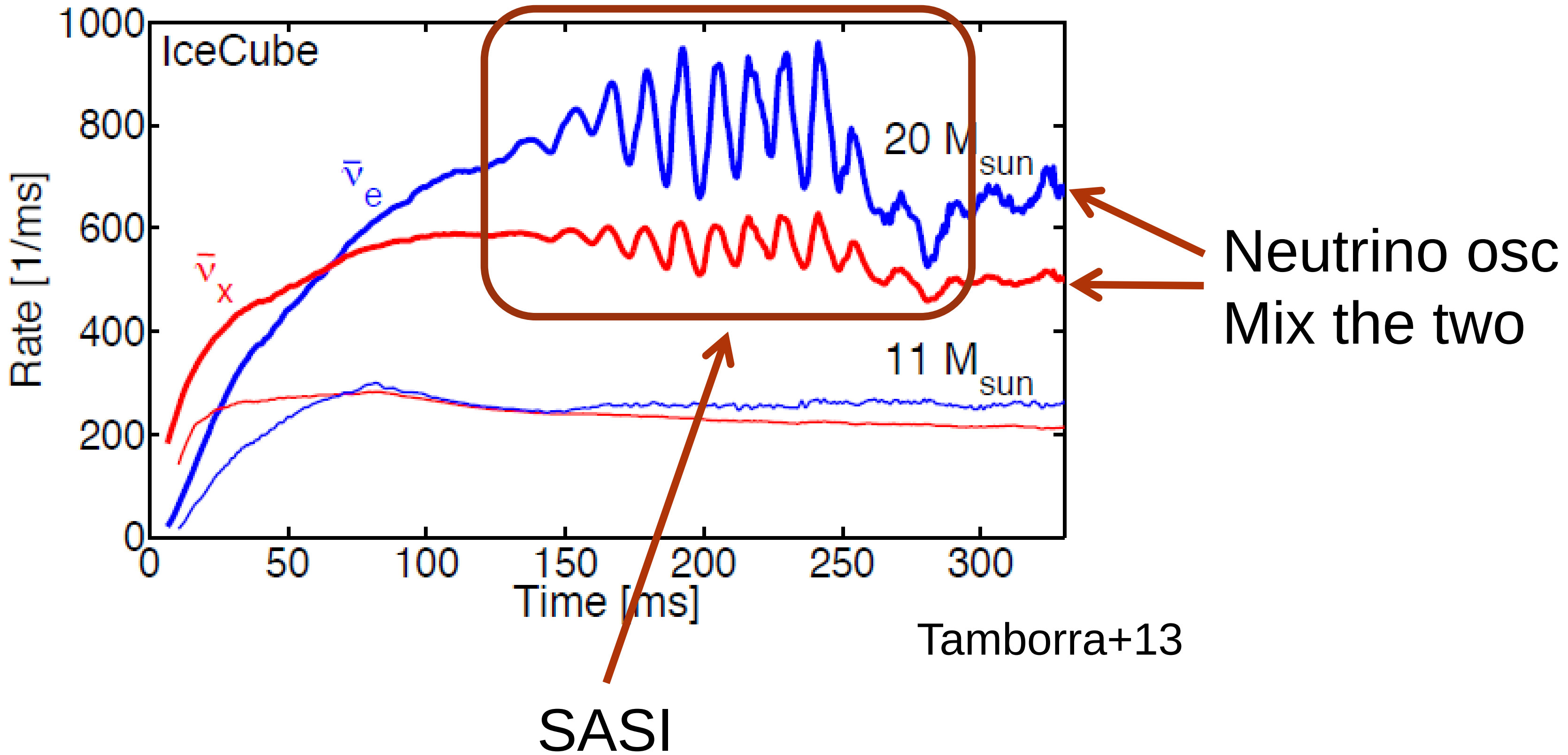
Gravitational Wave

Convection and SASI can be identified by the observation of GW.



Mueller+13

Neutrino



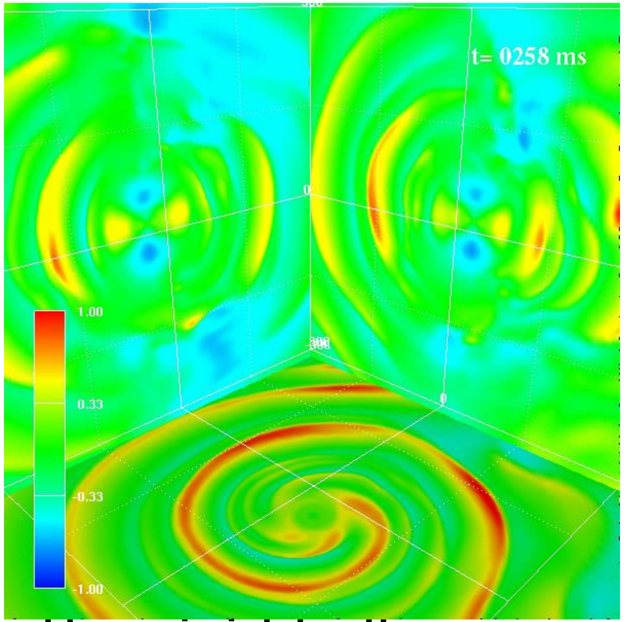
Tamborra+13

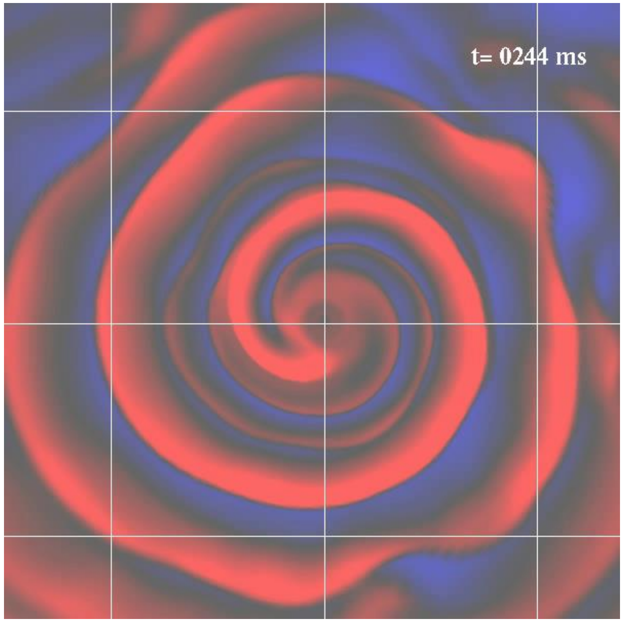
What helps neutrino heating?

1. Convection
2. SASI
   (Standing Accretion Shock Instability)
3. Rotation(Bar mode or spiral-SASI)
4. Magneto-Rotational Instability

Rotation

Rapid Rotation => spiral instability





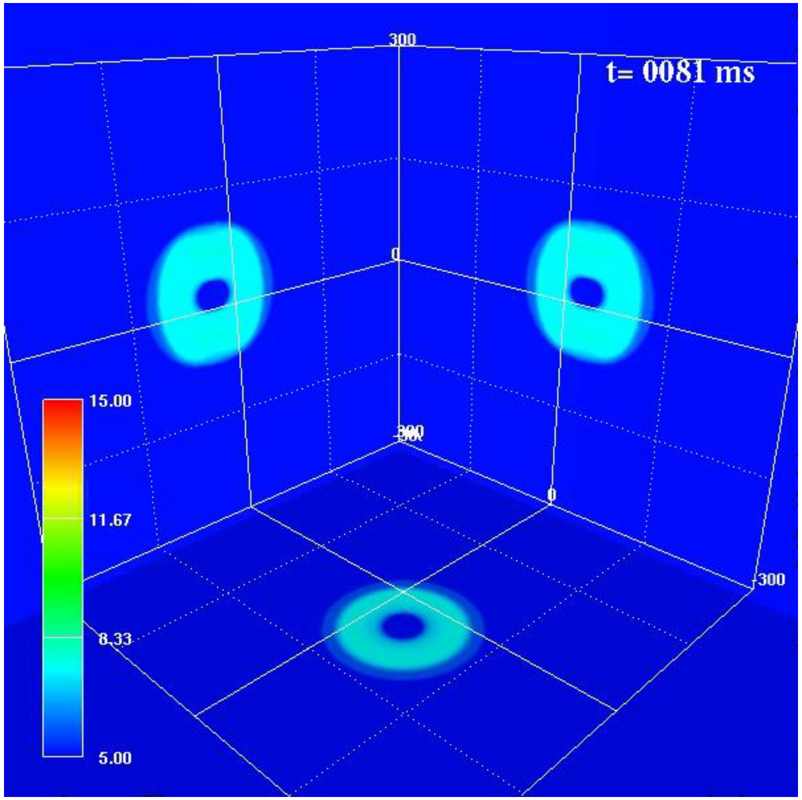
In the rigid ball,

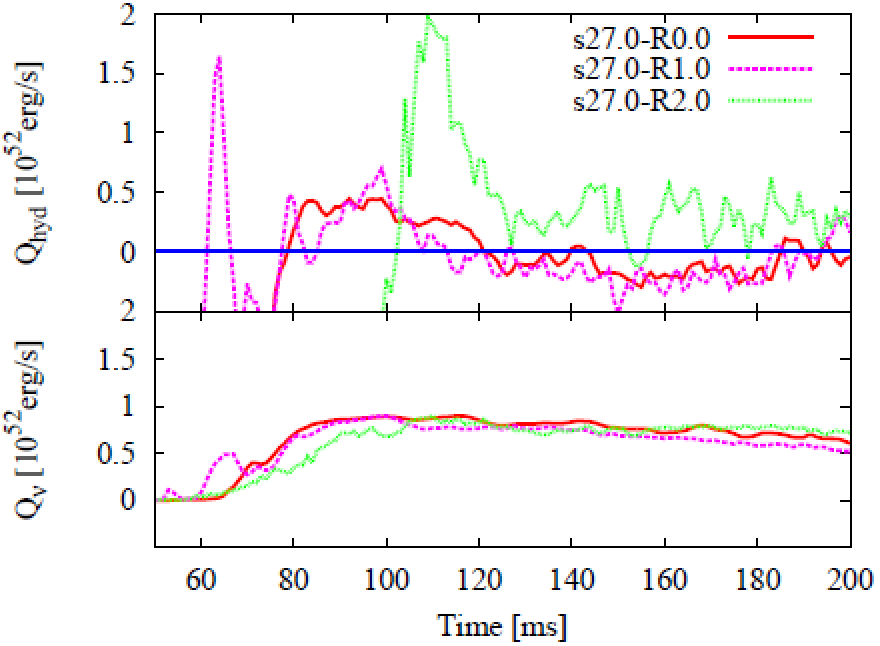
Rotational energy(T)/gravtational energy(W)=14%

In SNe case, criteria becomes smaller.

Called low-T/W instability

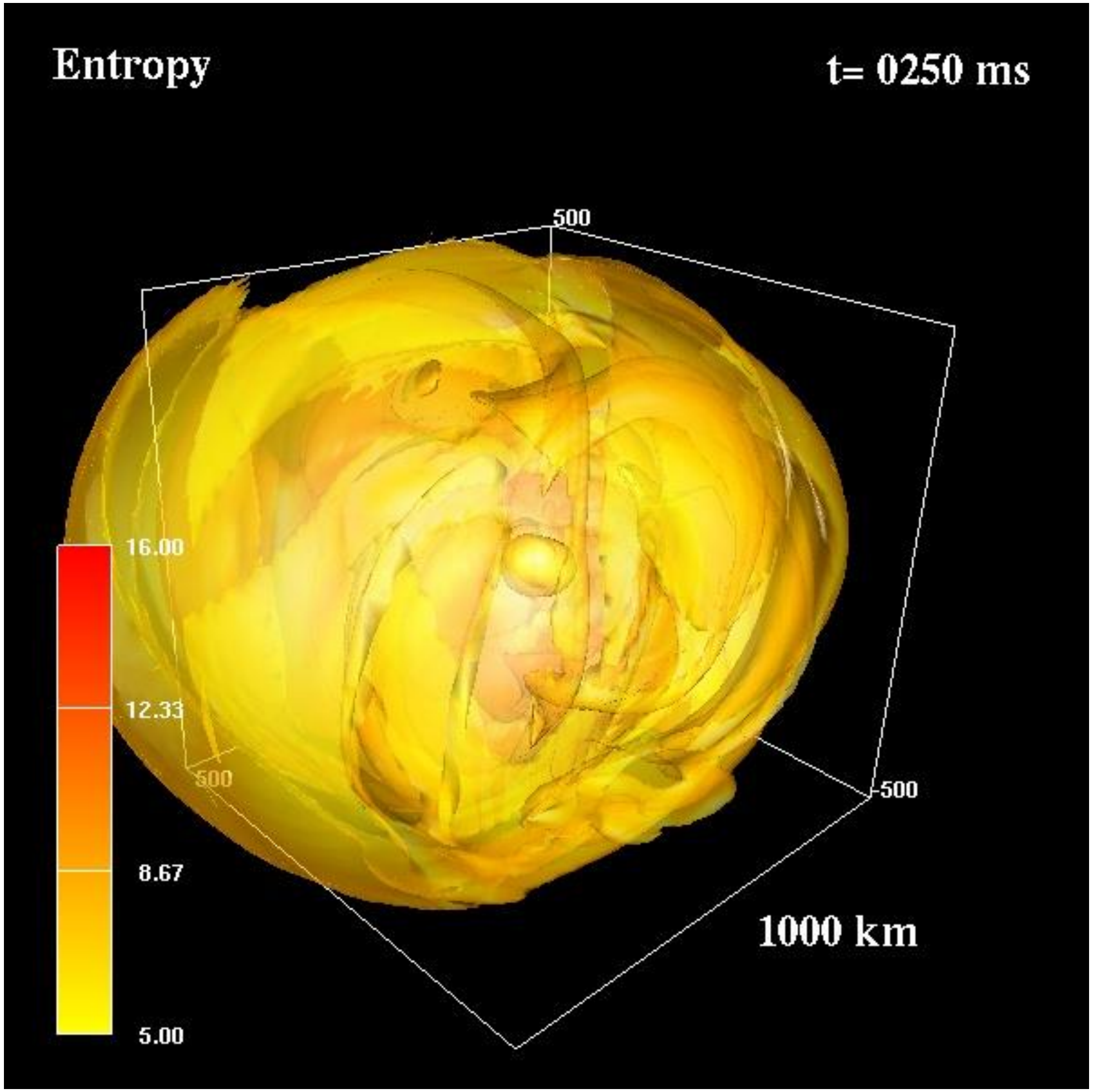
Rotation





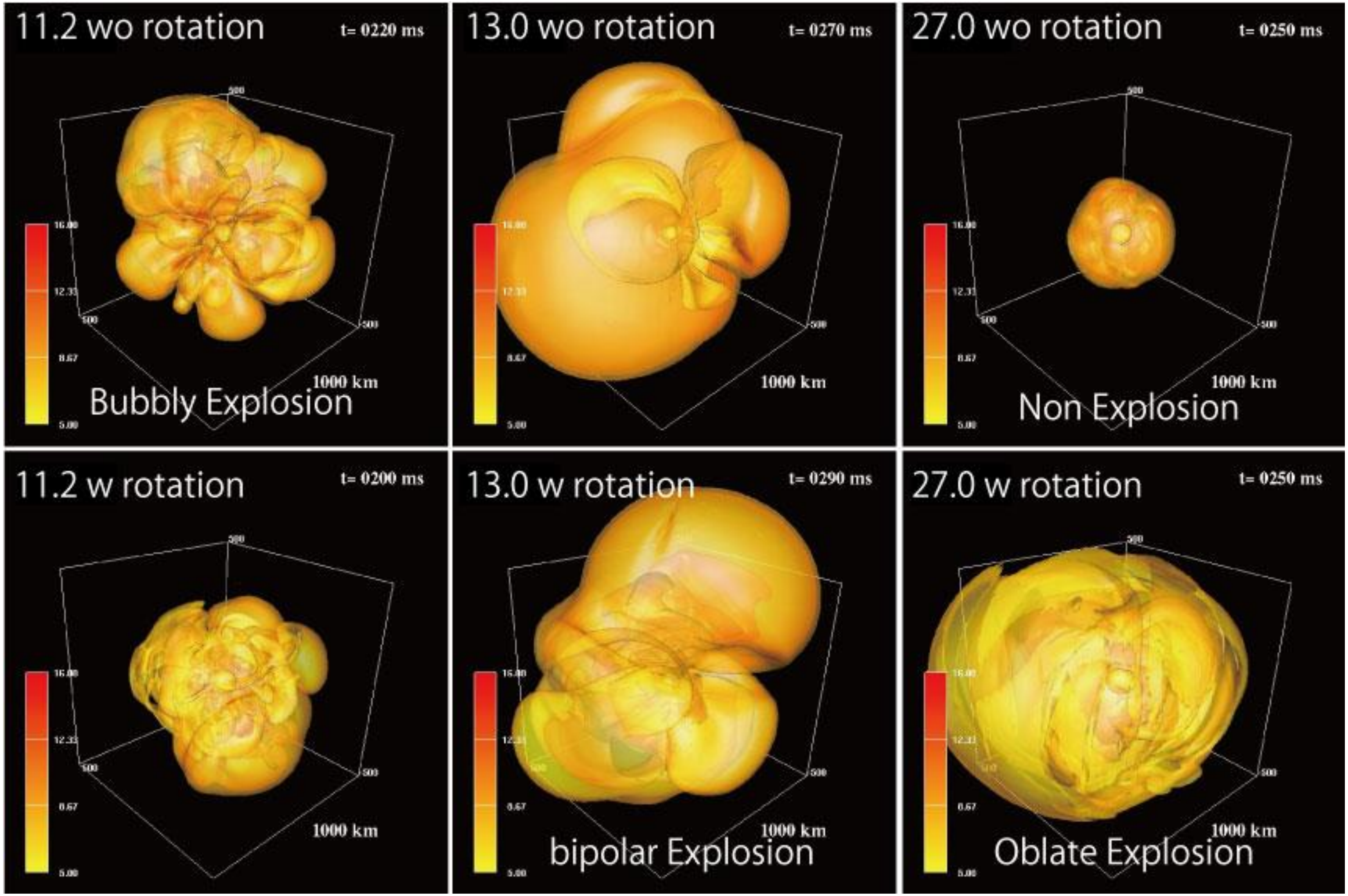
Spiral wave transfer the energy to the outer regon.
Finally explosion is found!

Rotation



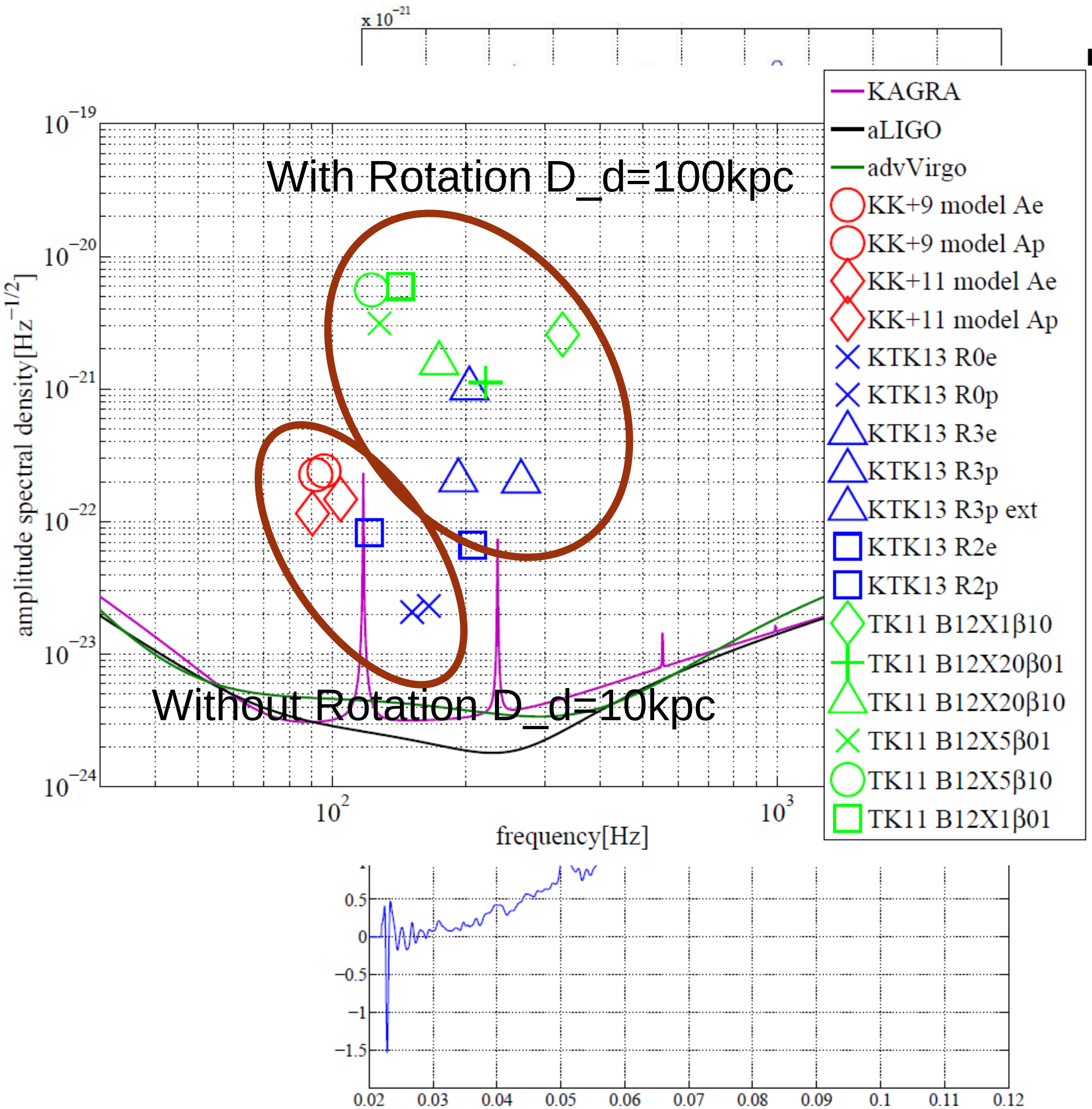
Strong expansion is found at equatorial plane

(see also Nakamura+14 and Iwakami+14)

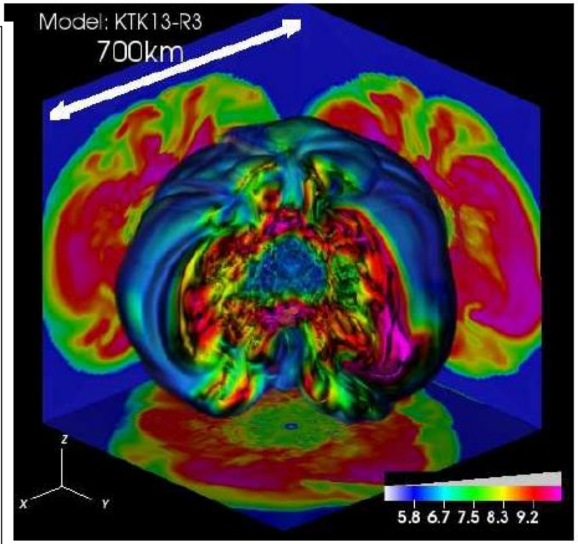


The mass of the progenitor and rotation make various type of Explosion(or Non Explosion).

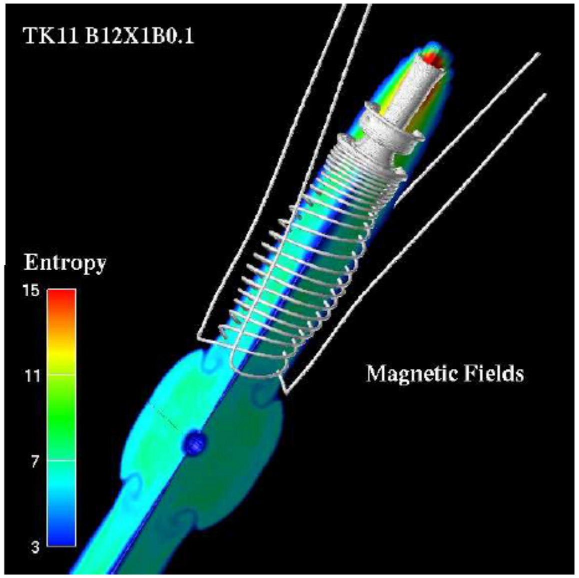
Gravitational wave



(e) TK11B12X1B01 waveform



(d) KTK13 R3p image



(f) TK11B12X1B01 image

What helps neutrino heating?

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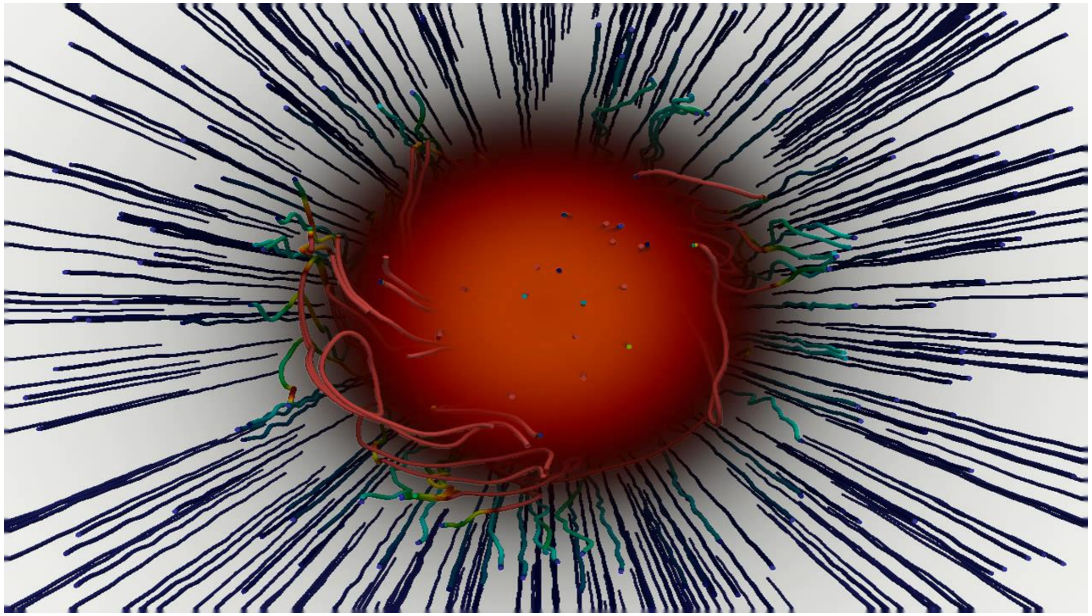
Magnetic Field



80km

MRI can also play important role! Masada+ in prep

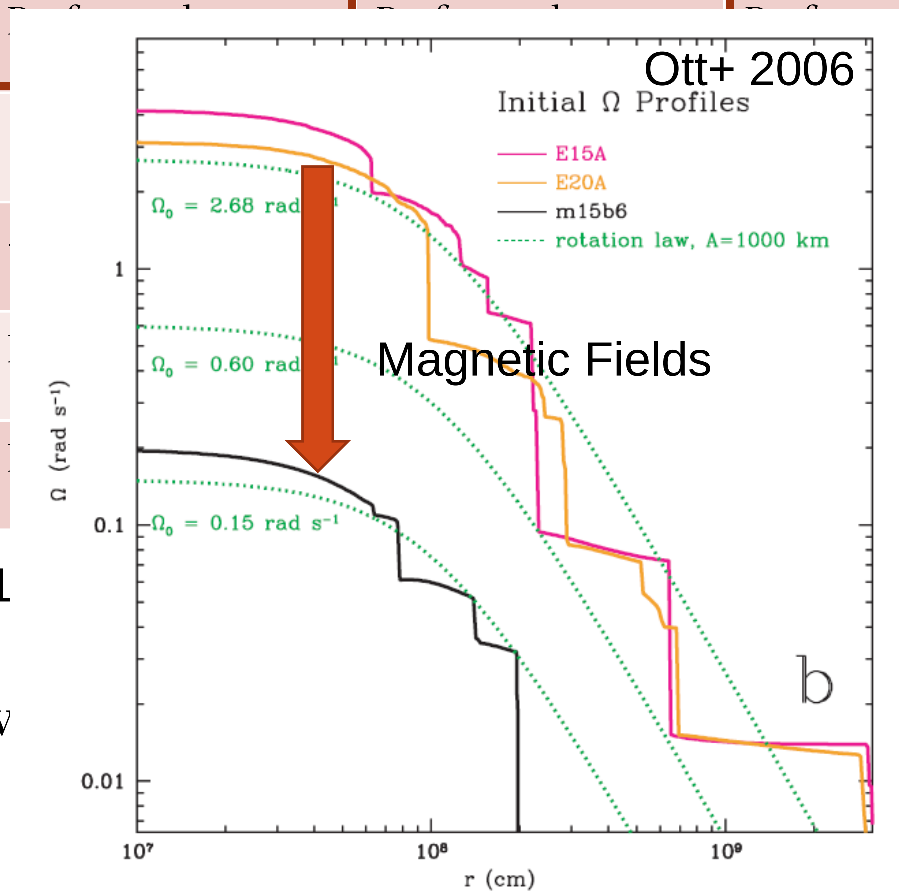
MRI can make strong turbulence near the neutrino sphere and increase neutrino luminosity.

Summary

- Supernova does not explode only by the ν -heating.
- Various hydrodynamic effect helps the heating. Some of them is promising!
- Observation of GW, neutrino, photon can uncover which effect really occur in the supernovae!

Progenitor dependence and Effect of rotations

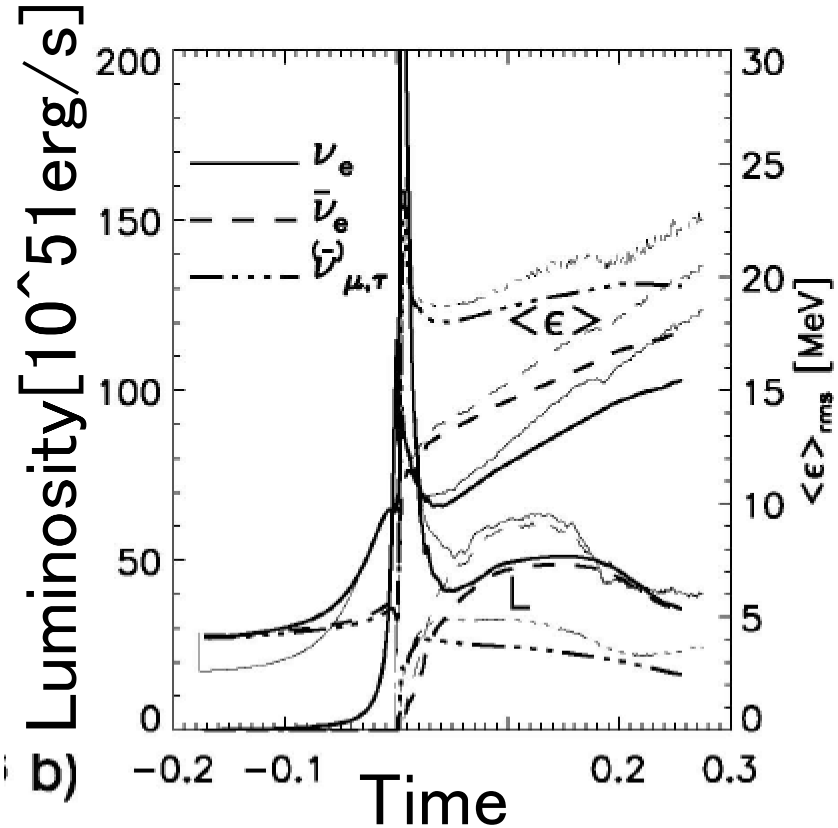
Initial angular velocity	s11.2	N13	s27
0 rad/s			d
0.3rad/s			
0.5ras/s			
1.0rad/s			d
2.0rad/s			d



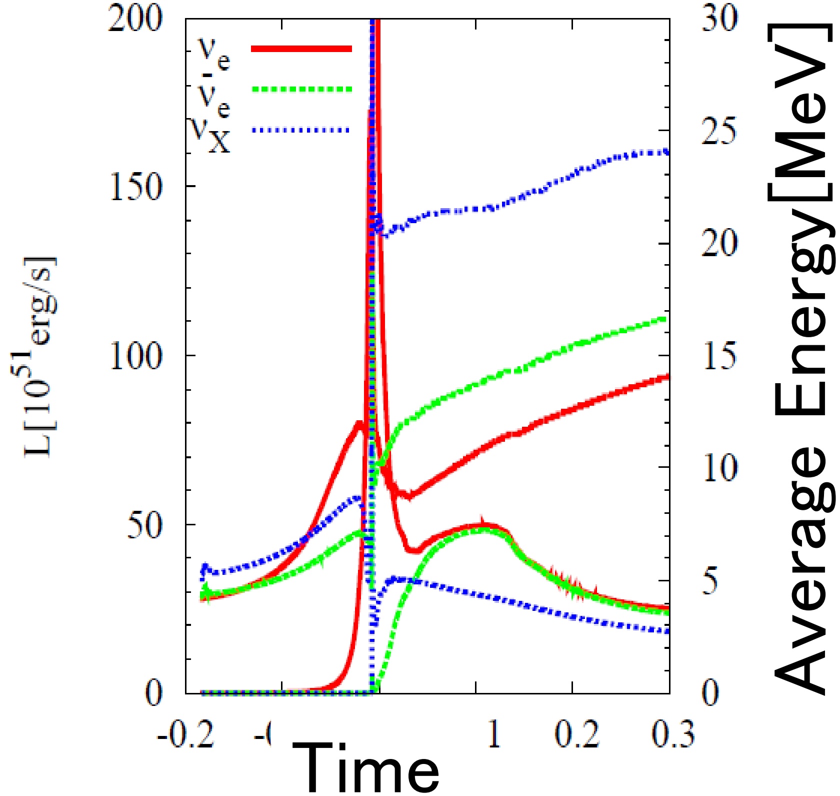
Compare these 1

Different flow ... n shape.

Comparison of IDSA & Sn & VE



Liebendoerfer et al 2005



Our newest version of IDSA

Sn and VE

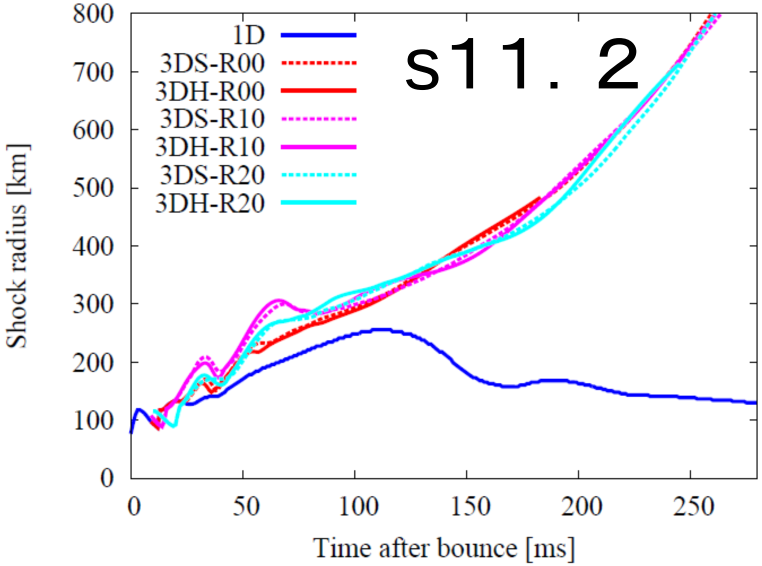
General relativistic simulation

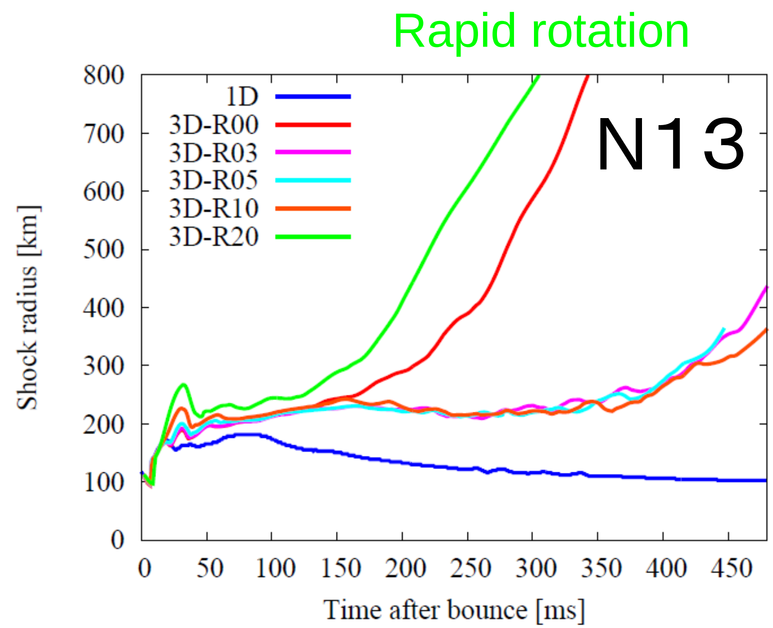
ecp,aecp,eca,csc,nsc,pap,nes,nbr

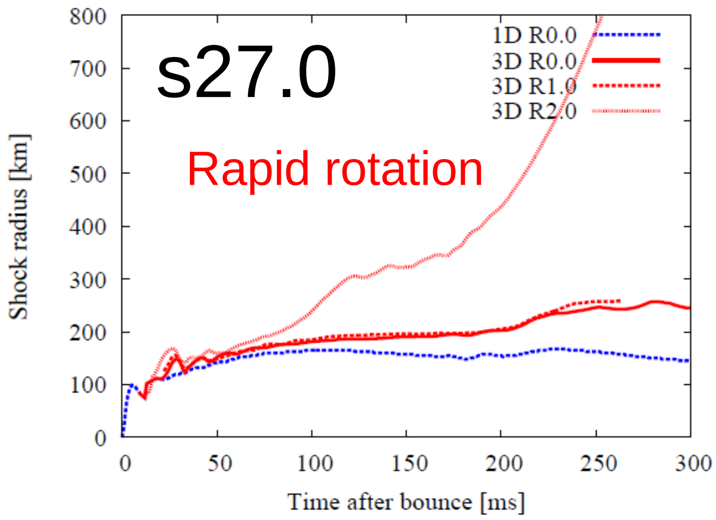
Newtonian Gravity

For simple spherical computation, the result is rather consistent.

Does rotation affect the shock revival?







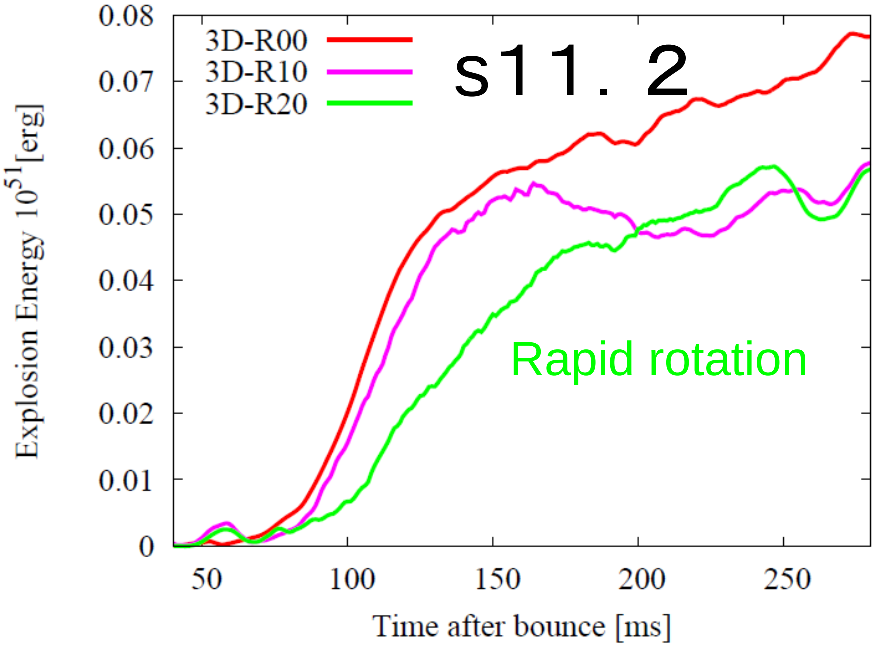
1D=> no shock revival

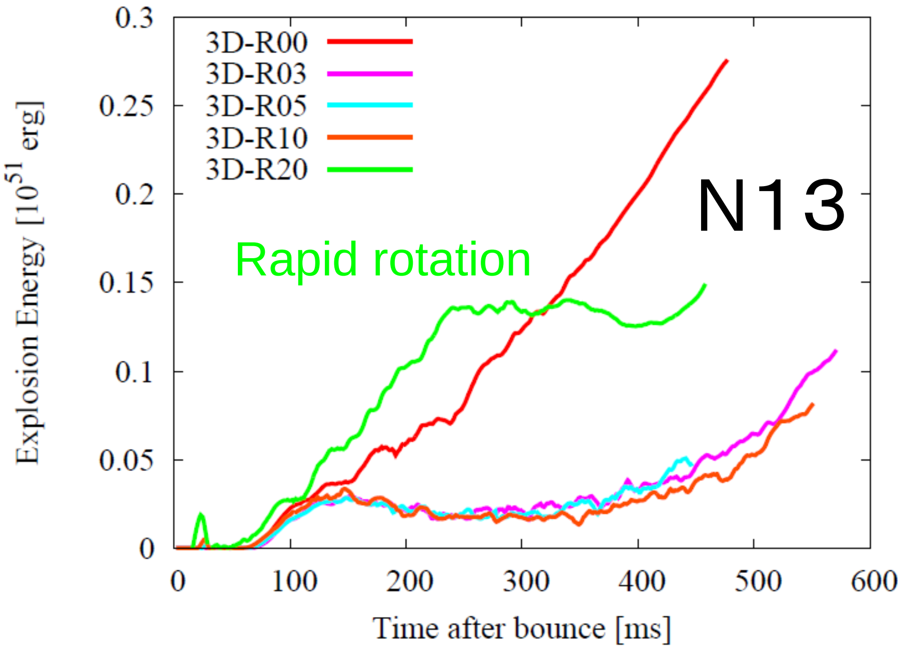
s11.2 : No

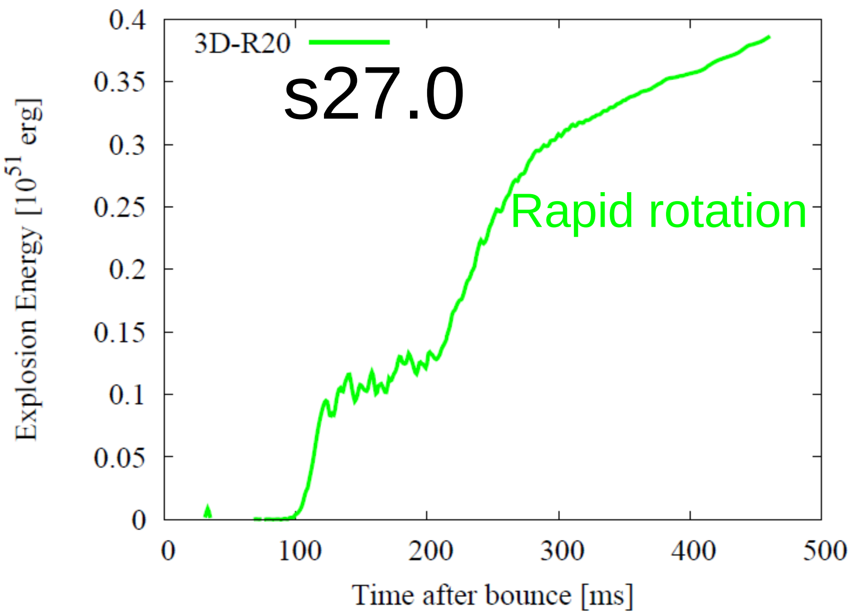
N13 : Yes

s27 : Yes

How energetic is that?

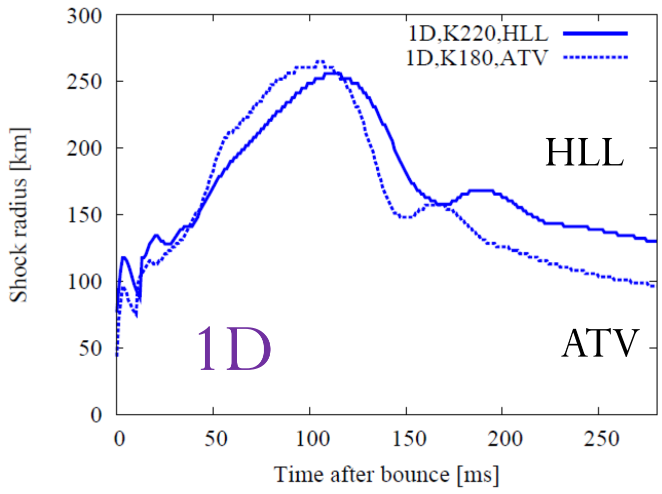


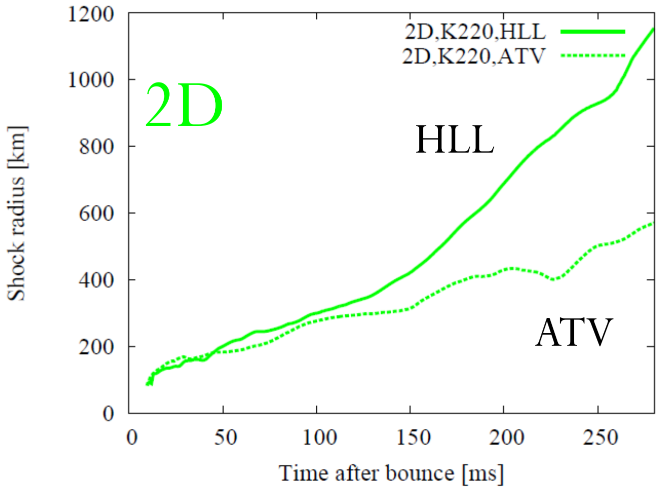


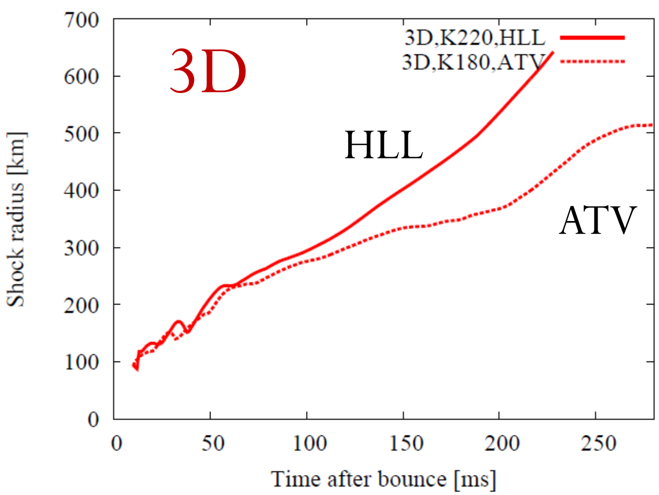


Observe 0.1-0.4 10^51erg!
It’s close to 10^51 erg!

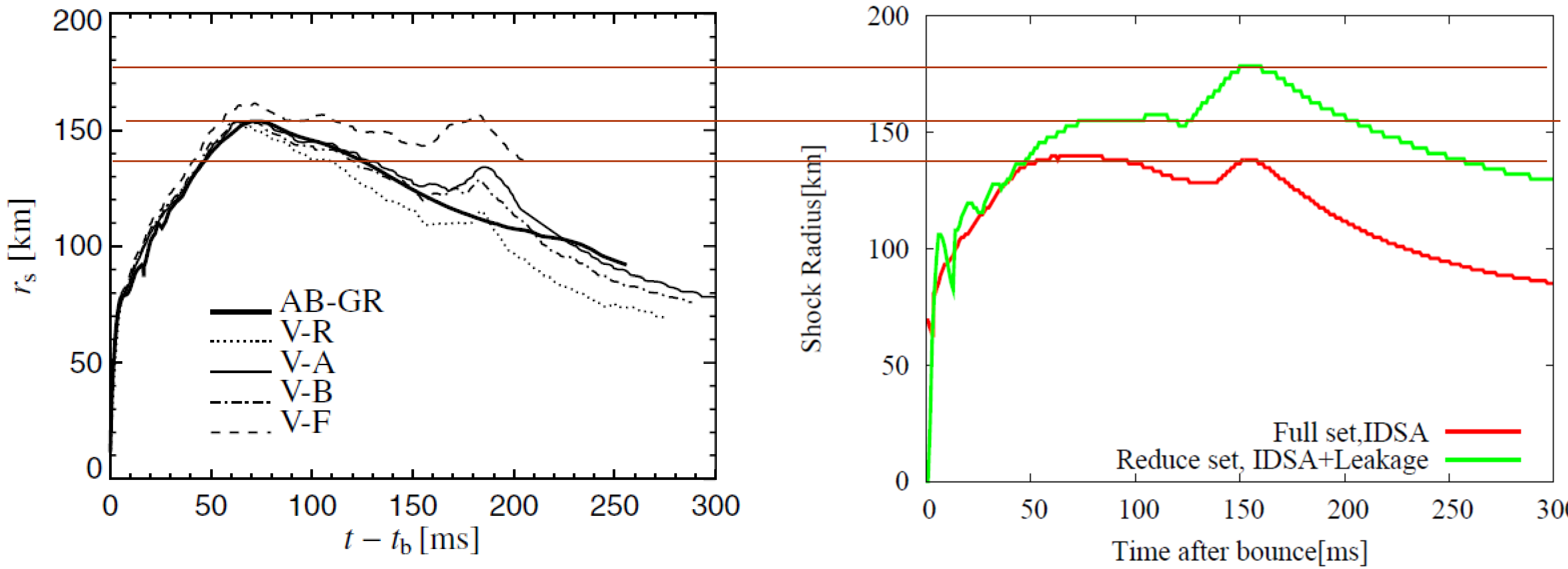
Viscosity as the hidden parameter





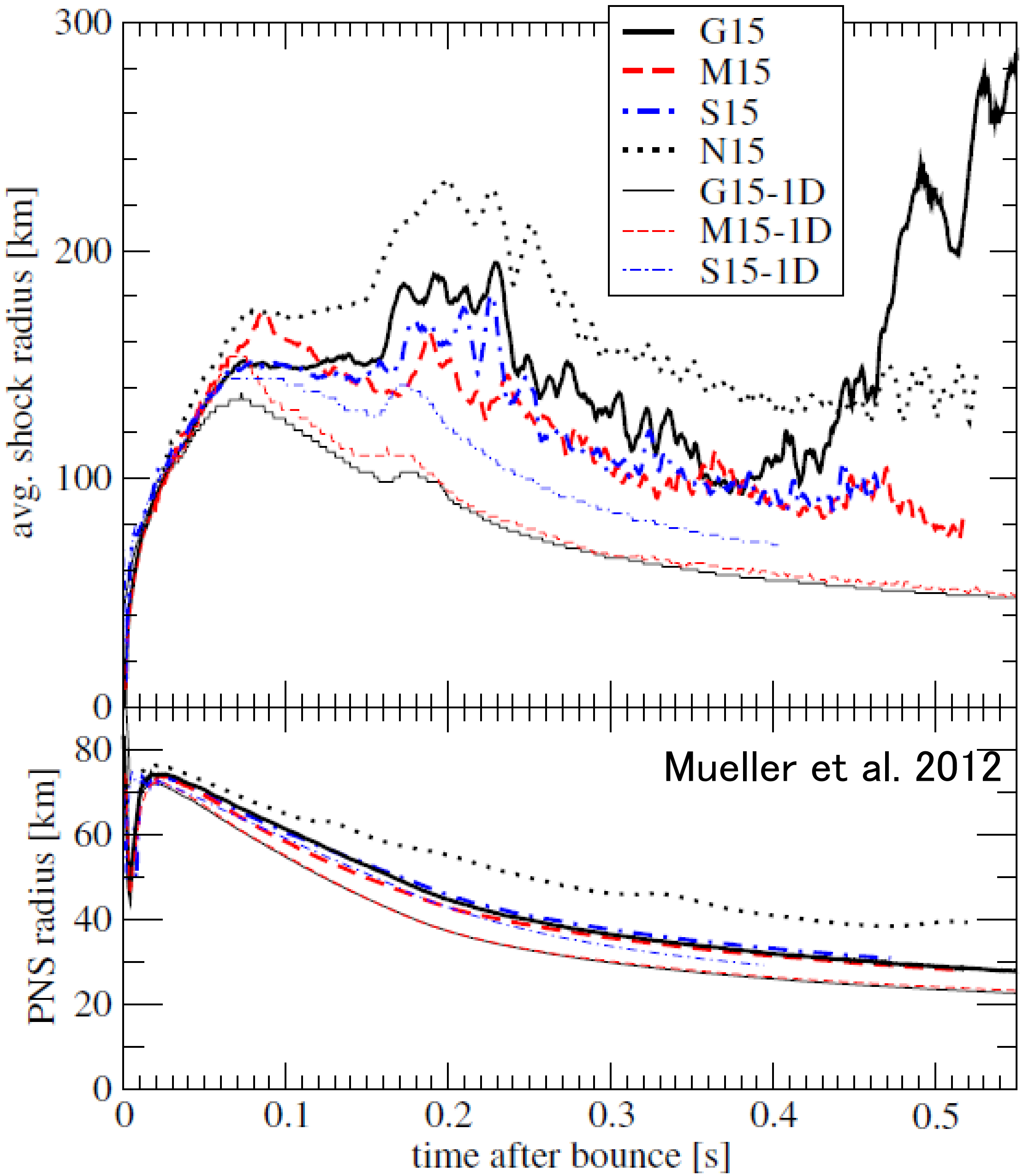


Comparison of the shock radius



Marek et al. 2006

Our simulation overestimates the shock radius compared to that of the new version (but new version may underestimate that?).



For early evolution,

Newtonian =>optimistic

Effective GR =>pessimistic

Full GR is important